

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
21 December 2007 (21.12.2007)

PCT

(10) International Publication Number
WO 2007/147053 A2

(51) International Patent Classification:
E21B 43/00 (2006.01)

(21) International Application Number:
PCT/US2007/071213

(22) International Filing Date: 14 June 2007 (14.06.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/813,475 14 June 2006 (14.06.2006) US

(71) Applicant and

(72) Inventor: **KASEVICH, Raymond, S.** [US/US]; 9 Mountain Road, Mt. Washington, MA 01258 (US).

(74) Agents: **ROBBENOLT, Paul, J.** et al.; Dorsey & Whitney LLP, Intellectual Property Department, 50 South Sixth Street, Suite 1500, Minneapolis, MN 55402-1498 (US).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM,

AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: IN-SITU RADIOFREQUENCY HEATING OF OIL SHALE TO ACHIEVE PHYSICAL UPGRADING, AND OIL AND GAS RECOVERY

(57) Abstract: The present invention is based on the in-situ application of radiofrequency energy to an oil shale volume by means of electromagnetic structures that may be of the bounded wave type (parallel wire transmission lines, resonant cavities, etc.) or unbounded wave type (antennas, or antenna arrays) arranged in the subsurface environment to achieve the desirable thermal radiation pattern and fracture pattern to achieve optimum coupling of radiofrequency energy to the targeted oil shale volume. The radiofrequency system is designed to provide power to the oil shale in a manner that gives precise temperature control of the chemical conversion of the kerogen to high quality oil with a minimum of surface upgrading and refining. Additional chemical conversion equipment may be provided in the sub-surface environment to insure the best chemical reactions in Kerogen are possible by radiofrequency heating.



WO 2007/147053 A2

IN-SITU RADIOFREQUENCY HEATING OF OIL SHALE TO ACHIEVE PHYSICAL UPGRADING, AND OIL AND GAS RECOVERY

FIELD OF THE INVENTION

[001] The present invention relates generally to the use of radiofrequency energy to a volume of oil shale in situ in order to upgrade the oil and more efficiently and effectively recover oil and gas from the oil shale.

BACKGROUND OF THE INVENTION

[002] Oil shale presents problems in oil recovery and production. The recovery of oil from oil shale is difficult and expensive. Further, even after recovering such oil, refining it remains expensive and time consuming. Thus, a system and method that facilitates the recovery and refinement of oil from oil shale would be beneficial. The present invention applies radiofrequency energy to oil shale in situ to heat the oil shale, thereby facilitating the in situ upgrading and recovery of the oil.

BRIEF SUMMARY OF THE INVENTION

[003] The present invention is based on the in-situ application of radiofrequency energy to an oil shale volume by means of electromagnetic structures that may be of the bounded wave type (parallel wire transmission lines, resonant cavities, etc.) or unbounded wave type (antennas, or antenna arrays) arranged in the subsurface environment to achieve the desirable thermal radiation pattern and fracture pattern to achieve optimum coupling of radiofrequency energy to the targeted oil shale volume. The radiofrequency system is designed to provide power to the oil shale in a manner that gives precise temperature control of the chemical conversion of the kerogen to high quality oil with a minimum of surface upgrading and refining. Additional chemical conversion equipment may be provided in the sub-surface environment to insure the best chemical reactions in Kerogen are possible by radiofrequency heating.

[004] Heating rates are critical for the control of chemical reaction times for oil recovery from oil shale by thermal methods. Radiofrequency heating applied to oil and gas recovery from oil shale has the ability to carefully control temperature distributions

throughout the treatment volume and heating rates to insure high quality oil recovery with a minimum of cracking or conversion of oil to coke. In addition, radiofrequency energy will cause formation fractures to provide enhanced permeability for optimizing oil/gas recovery. In-situ temperature and radiofrequency power adjustments by modulation of the radiofrequency waveform during radiofrequency heating is fundamental to achieving high quality oil recovery with useable gas recovery. This is because coking reactions depend strongly on heating rates and these reactions are a major source of intraparticle oil degradation. The combination of in-situ borehole radiofrequency apparatus for directive heat application and either magnetic or electrical borehole and surface impedance tomography for temperature mapping the resistivity of the produced fluids underground insures that the rate of radiofrequency power application is correct to insure the proper kinetic and decomposition chemical pathway for a high quality oil product recovery. In addition, rapid radiofrequency pulse application avoids the need to heat the entire mass of oil shale rock. Short periods of intensive radiofrequency heating followed by longer periods of weaker heating of oil shale can result in an abrupt change in chemical dynamics or rapid change in dielectric constant which allows the radiofrequency energy to be selectively absorbed by the bitumen (intense period) followed by lower temperature recovery of high quality oil over longer periods of time. The intense period will remove significant gas and water from the oil shale which will improve permeability for efficient recovery.

[005] In one embodiment of the invention, a system for treating and recovering oil in oil shale is provided. The system may comprise a borehole in an oil shale field, a radiofrequency energy applicator positioned within the borehole, a cable attached to the radiofrequency energy applicator to supply radiofrequency to the applicator, a radiofrequency generator attached to the cable to generate radiofrequency to be supplied to the radiofrequency energy applicator, and a production well in the oil shale filed for recovery of oil.

[006] In another embodiment of the invention, a system for treating and recovering oil in oil shale is provided. The system may comprise a borehole in an oil shale field, a radiofrequency energy applicator positioned within the borehole, a cable

attached to the radiofrequency energy applicator to supply radiofrequency to the applicator, a radiofrequency generator attached to the cable to generate radiofrequency to be supplied to the radiofrequency energy applicator, and a product return pipe running through the borehole, the product return pipe comprised of a distal end positioned in the vicinity of the radiofrequency energy applicator through which oil or other products may be recovered and a proximal end on or near the surface of the ground.

[007] In yet another embodiment of the invention, a method for treating and recovering oil in oil shale is provided. The method comprises the steps of positioning a radiofrequency energy applicator in a borehole in an oil shale field, generating radiofrequency energy, applying the radiofrequency energy to the oil shale with the applicator to heat the oil in the oil shale, and recovering oil through a production well.

[008] While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. As will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[009] Fig. 1 is a view of the oil shale radiofrequency system of the invention from a sub-surface perspective.

[010] Fig. 2 shows a sub-surface perspective view of an alternative arrangement of the oil shale radiofrequency system of the invention.

[011] Fig. 3 is a perspective view of a radiofrequency borehole antenna apparatus for use in the present invention.

DETAILED DESCRIPTION

[012] A variety of different types of down hole electromagnetic structures may be employed to apply radiofrequency energy to oil shale. The proper structure for any

particular application depends on a variety of factors, including depth, heat uniformity, and minimizing the degree of coking and production of unsaturated hydrocarbons. Furthermore, such electromagnetic structures may be configured in a variety of different arrangements. The proper arrangement may depend upon a number of factors, including geography, field size and shape, and shale characteristics.

[013] Fig. 1 is a view of the oil shale radiofrequency system of the invention from a sub-surface perspective. The system is arranged in oil shale 10. Oil and gas production well 12 is drilled into oil shale field 10 for recovery of oil and gasses. At least a portion of production well 12 is drilled horizontally through the oil shale field, as represented by horizontal portion 14. Horizontal production well 14 is positioned to receive oil and gasses that are moved or generated due to the application of radiofrequency energy. A second well, radiofrequency well 16, is drilled into the oil shale in proximity to production well 12. At least a portion of radiofrequency well 16 is drilled horizontally through the oil shale in proximity to and above horizontal production well 14, as represented by horizontal radiofrequency well 18. Horizontal radiofrequency well 18 is used to apply radiofrequency energy to the surrounding oil shale, thereby heating the oil upgrading it in situ, and facilitating the recovery of oil and gasses. Due to gravity, the oil drains, where it may be captured by and pumped out through production well 12 to storage or processing equipment (not pictured).

[014] Radiofrequency energy is generated by a radiofrequency generator (not pictured). The radiofrequency generated thereby is transmitted via radiofrequency transmission line 20 through radiofrequency well 16 and horizontal radiofrequency well 18 to radiofrequency antenna 22. Radiofrequency antenna 22 applies radiofrequency energy to the surrounding oil shale, thereby physically upgrading and refining it. The heating of the oils shale also facilitates recovery of the oil and the resulting gasses through production well 12. Production well 12 also may act as a parasitic antenna to redirect radiation in an upward direction toward the targeted oil shale, thereby increasing efficiency.

[015] Radiofrequency antennas may be arranged in an oil shale field in numerous configurations to maximize physical upgrading and recovery of the oil and

resulting gasses. Fig. 2 shows a sub-surface perspective view of an alternative arrangement of the oil shale radiofrequency system of the invention. Radiofrequency antennas 22 may be placed in proximity to one another in oil shale 10. For these purposes, radiofrequency antennas 22 may be placed vertically, horizontally, or both. Radiofrequency energy generated by a radiofrequency generator (not pictured) is supplied to the antennas 22 and then applied to oil shale 10. Again, the resulting heating upgrades the oil and facilitates recovery of the oil and resulting gasses. The oil drains due to gravity. Horizontal production well 21 is positioned below the antennas 22 to collect and recover the heated oil and gasses.

[016] Fig. 3 is a perspective view of a radiofrequency borehole antenna apparatus for use in the present invention. Applicator system 30 is positioned within borehole 32. Borehole 32 is supported by casing 34. Applicator system 30 is then used to apply radiofrequency energy to the oil shale in the vicinity of borehole 32.

[017] Applicator structure 40 is a transmission line retort. For a point of reference, a typical applicator 40 may be approximately 70 feet long. In a typical configuration, the applicator 40 may be positioned from between 100 to 600 feet underground in borehole 32. Radiofrequency energy is supplied to applicator 40 by a radiofrequency generator (not shown). The radiofrequency generator is connected to applicator 40 via a portion of flexible coaxial cable 50. In turn, the flexible coaxial cable 50 is connected to a portion of rigid coaxial cable 52. The coaxial cable may or may not be supported by ceramic beads 54, which are desirable at higher temperatures. By this means, the radiofrequency generator supplies radiofrequency energy to applicator 40, which in turn applies radiofrequency energy to the targeted oil shale. This allows in situ upgrading of the oil and facilitates recovery.

[018] Recovery of the oil and related products is achieved by means of production pipe 60. This non-metallic pipe runs from the production area of borehole 32 through the borehole to surface 36. At the surface, production pipe 60 is connected via a product return line to a storage or processing facility (not shown).

[019] Production pipe 60 provides a firm mounting base for the radiofrequency hardware of applicator system 30. Coaxial cables 50 and 52 can be attached directly to

production pipe 60 using connectors 62. Applicator 40 also attaches to production pipe 60.

[020] Although a specific example of an applicator structure is given, it is understood that other arrangements known in the art could be used as well. Uniform heating may be achieved using antenna array techniques, such as those disclosed in U.S. Patent No. 5,065,819. Such techniques can be used to minimize coking conditions at the applicator borehole and avoid excessive electrode voltage gradients at high power. Arrays reduce excessive voltage gradients at the borehole by means of mutual coupling. The ability to separately measure reflected power from each applicator borehole containing radiator and mutual impedance coupling between any pair of applicator boreholes insures precise temperature control of the heated volume.

[021] Other variations are possible, including non-radiation structures such as those proposed in J. Bridges, et al., "RF Heating of Utah Tar Sands," Final Report, IIT Research Institute. However, such structures are sensitive to high voltage breakdown and require extensive drilling which is not economical.

[022] In use, a user of an embodiment of the present invention would position an applicator system in a borehole in an oil shale field. The user would position the applicator structure itself in the borehole in the oil shale for application of radiofrequency energy. The user would connect the applicator structure to a radiofrequency generator via coaxial cable. A production pipe would run from the area of production to the surface, and from there to a storage or processing facility. The user would then apply radiofrequency energy using the radiofrequency generator to the applicator, thereby applying the radiofrequency energy to the oil shale. High power radiofrequency transmitters of 50,000 watts may be used with frequencies in the 13 to 15 MHz frequency range. The radiofrequency energy would be controlled to minimize coking and achieve the desired upgrading of the oil. The various hydrocarbon gases are produced in the oil shale at specific temperatures and are well documented in the literature. The resulting products would then be recovered via the production pipe and transferred to a storage or processing facility.

[023] The modulation waveform of the radiofrequency power is chosen to minimize the coupling of energy to the mineral component of the oil shale rock but at the same time speeding the chemical reaction of the kerogen from bitumen to light oil without coking or oil degradation. The minimum coupling achieves an economic advantage through selective heating thereby reducing the overall cost of the energy required to operate the radiofrequency equipment. High power microwave heating of oil shale can cause an abrupt change in the oil shale dielectric constant. This implies that at radiofrequencies, intense power for short time duration can bring about the production of oil and gas without having to wait for significant time to occur as in conventional heating. This methodology should result in a significant overall energy savings.

[024] The entire subsurface radiofrequency process is controlled by a combination of electrical transmission line impedance measurements at the wellheads, measurement of gas and oil production rates during treatment and the employment of tomography imaging techniques, such as those described in Patent Application No. PCT/US2006/002097 that allow the operators to see where the fluids are being produced, what pathways they are following to the recovery wells, and actual temperatures occurring in the formation.

[025] Finally, the oil shale may be treated at lower temperatures by using the revolving field concept described in U.S. Patent No. 6,413,399 to Kasevich for soil remediation in conjunction with radiofrequency heating. Subsurface temperatures created in the oil shale by this method will reduce the initial amount of connate water in the formation and thereby give a higher selective heating advantage with controlled fracture zones for enhanced permeability. Both radiofrequency and application of the Revolving Field will provide fracturing but the use of 60Hz electrical 3 phase power for fracturing is expected to provide significant enhancement of gas and fluid permeability for controlled and directed recovery of oil and gas during and after heating with radiofrequency energy.

CLAIMS

What is claimed is:

1. A system for treating and recovering oil in oil shale, said system comprising:
 - a borehole in an oil shale field;
 - a radiofrequency energy applicator positioned within the borehole;
 - a cable attached to the radiofrequency energy applicator to supply radiofrequency to the applicator;
 - a radiofrequency generator attached to the cable to generate radiofrequency to be supplied to the radiofrequency energy applicator; and
 - a production well in the oil shale filed for recovery of oil.
2. The system of claim 1 wherein the applicator is an antenna array.
3. The system of claim 1 wherein said applicator is a solenoid antenna.
4. The system of claim 1 wherein the applicator is a helical antenna.
5. A system for treating and recovering oil in oil shale, said system comprising:
 - a borehole in an oil shale field;
 - a radiofrequency energy applicator positioned within the borehole;
 - a cable attached to the radiofrequency energy applicator to supply radiofrequency to the applicator;

a radiofrequency generator attached to the cable to generate radiofrequency to be supplied to the radiofrequency energy applicator; and

a product return pipe running through the borehole, the product return pipe comprised of:

a distal end positioned in the vicinity of the radiofrequency energy applicator through which oil or other products may be recovered; and

a proximal end on or near the surface of the ground.

6. A method for treating and recovering oil in oil shale, the method comprising the steps of:

positioning a radiofrequency energy applicator in a borehole in an oil shale field;

generating radiofrequency energy;

applying the radiofrequency energy to the oil shale with the applicator to heat the oil in the oil shale; and

recovering oil through a production well.

7. The method of claim 6, further comprising the steps of:

controlling the radiofrequency energy applied to the oil shale in order to upgrade the oil in situ.

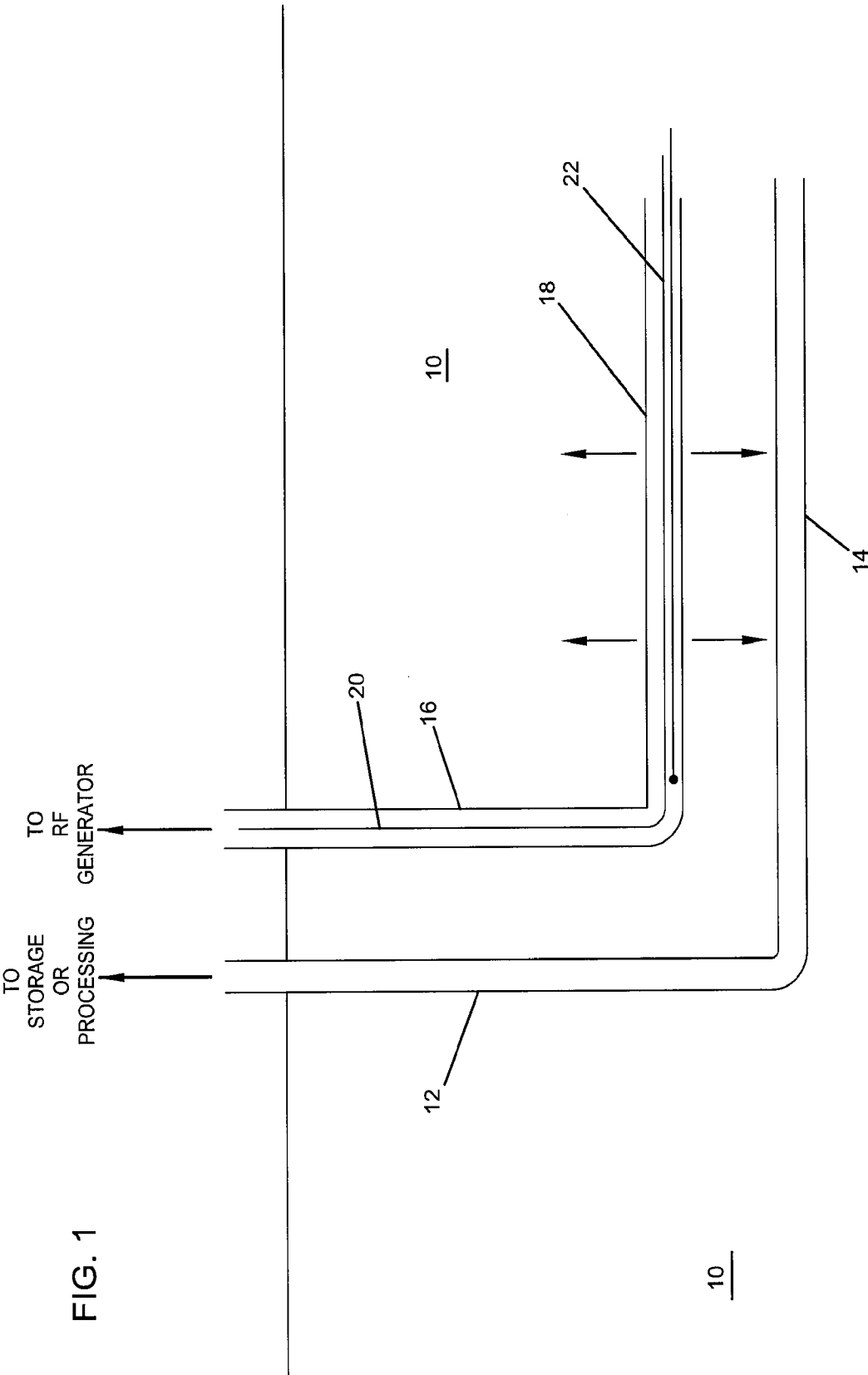


FIG. 1

FIG. 2

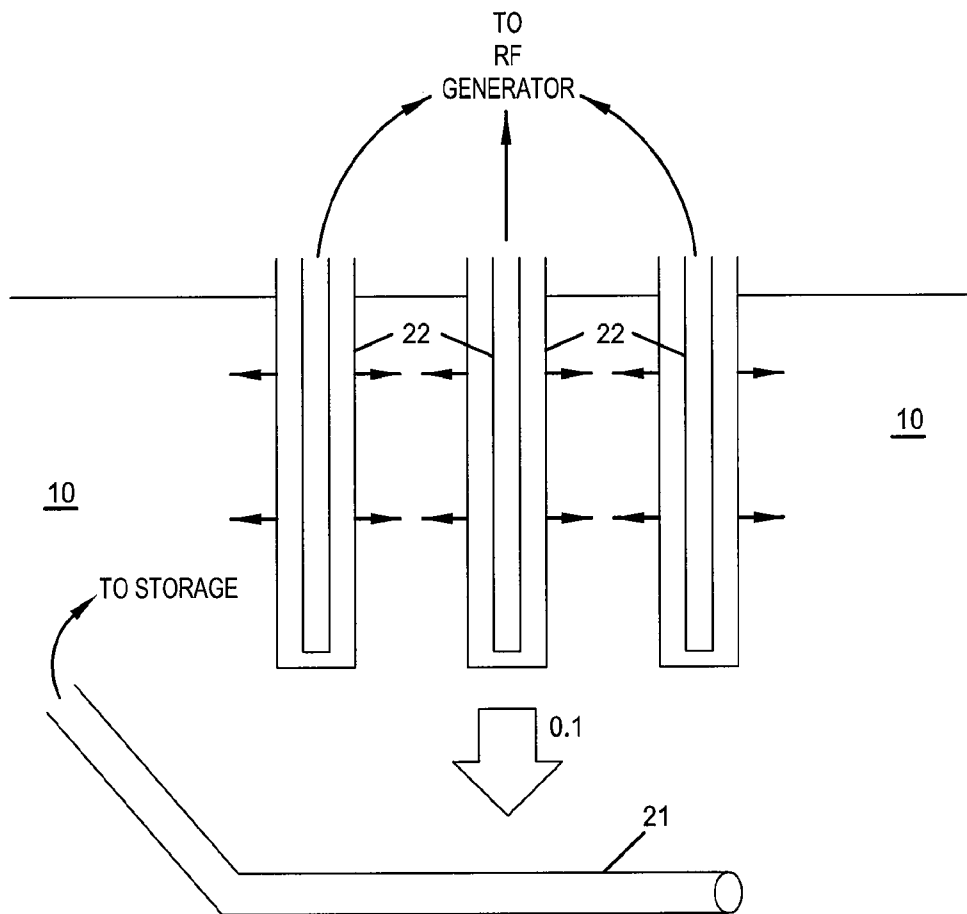


FIG. 3

